

TRANSMIT-RECEIVE FM-CW RADAR APPARATUS

Applicant claims the right to priority from, and
5 incorporates by reference the entire disclosure of,
Japanese Patent Application No. 2003-83083 which was
filed March 25, 2003.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to an FM-CW radar
apparatus that uses a frequency-modulated (FM) continuous
wave (CW) transmit signal and, more particularly, to a
transmit-receive FM-CW radar apparatus that uses a single
15 antenna and switches the antenna between transmission and
reception by time division.

2. Description of the Related Art

FM-CW radar is used as a radar system for
measuring the distance, the relative velocity, etc. of a
20 target object. As FM-CW radar can measure the distance
and the relative velocity of a vehicle traveling ahead by
using a simple signal processing circuit, and as its
transmitter and receiver can be constructed with simple
circuitry, this type of radar is used as an automotive
25 collision avoidance radar.

It is known to provide a single-antenna time
division control-type FM-CW radar that uses a single
antenna for both transmission and reception. For
example, there is disclosed a radar system in which
30 amplifiers are provided in the transmitter and receiver
signal paths, respectively, and switching between
transmission and reception is performed by operating the
transmitter amplifier and the receiver amplifier, in an
alternating fashion, in synchronism with the transmit and
35 receive timings (refer to Japanese Unexamined Patent
Publication No. 2002-122661).

The switching between transmission and

reception is performed by controlling the gains of the amplifiers and turning the amplifiers on and off. By controlling the gains of the amplifiers and turning the amplifiers on and off for switching between transmission and reception, the isolation between the transmitter and the receiver is increased to prevent the transmitter power from leaking via a transmit-receive switch to the receiving system.

10 SUMMARY OF THE INVENTION

In FM-CW radar, as the power of the received signal decreases with the fourth power of the distance to the target, the level of the received power greatly differs between the waves reflected from a short-range target and the waves reflected from a long-range target. As a result, a wide dynamic range is required of the receiver circuit, which leads to an increase in the cost of the receiver circuit.

It is an object of the present invention to provide a transmit-receive FM-CW radar that can properly detect targets and can properly process received signals according to the ranges of the targets, while achieving increased isolation between the transmitter and the receiver but without requiring an increase in the dynamic range of the receiver circuit.

In a transmit-receive FM-CW radar apparatus according to the present invention, an amplifier capable of controlling gain is provided in a transmitter signal path or a receiver signal path and, by using an amplifier gain controller, the amplifier provided in the receiver signal path is controlled so as to suppress the gain in the first half of a receive timing interval or the amplifier provided in the transmitter signal path is controlled so as to suppress the gain in the second half of a transmit timing interval; with this configuration, the dynamic range of the receiving system can be reduced.

In one preferred mode of the invention, amplifiers

are provided in both the transmitter and the receiver,
and the switching between transmission and reception is
performed by operating the amplifier provided in the
transmitter and the amplifier provided in the receiver in
5 an alternating fashion in synchronism with the transmit
and receive timings.

The gain is controlled in such a manner as to reduce
the amount of suppression gradually from the leading edge
toward the midpoint of the receive timing interval or
10 from the trailing edge toward the midpoint of the
transmit timing interval, thereby suppressing the
received power of the reflected wave from a short-range
target. Alternatively, the gain may be controlled in
such a manner as to reduce the amount of suppression
15 stepwise from the leading edge toward the midpoint of the
receive timing interval or from the trailing edge toward
the midpoint of the transmit timing interval.

In another preferred mode of the invention, a
plurality of amplifiers are provided in the receiver
20 signal path, and one of the amplifiers is used for
performing the switching between transmission and
reception, while the other one of the amplifiers is used
for suppressing the gain in the first half of the receive
timing interval.

25 The suppression of the gain or the switching between
transmission and reception by the amplifier is performed
by varying a voltage applied to the amplifier.

In a further preferred mode of the invention, a
multiplier capable of controlling power is provided in
30 the transmitter signal path or in a branch section,
branching off a directional coupler, in the transmitter
and, by using a power controller provided for the
multiplier, a voltage applied to the multiplier (M_t)
provided in the transmitter signal path is varied so as
35 to suppress power in the second half of the transmit
timing interval or a voltage applied to the multiplier
(M_r) provided in the branch section is varied so as to

suppress power in the first half of the receive timing interval.

According to the transmit-receive FM-CW radar of the present invention, by suppressing the power of the reflected wave, particularly from a short-range target, the dynamic range of the receiving system for receiving waves reflected from targets, not only at short range but also at long range, can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the accompanying drawings, wherein:

Figs. 1A, 1B, and 1C are diagrams for explaining the principle of FM-CW radar when the relative velocity with respect to a target is 0;

Figs. 2A, 2B, and 2C are diagrams for explaining the principle of FM-CW radar when the relative velocity with respect to a target is v ;

Fig. 3 is a diagram showing one configuration example of a single-antenna transmit-receive FM-CW radar;

Figs. 4A, 4B, 4C, and 4D are diagrams showing timings for transmission, reception, etc.;

Figs. 5A, 5B, 5C, and 5D are diagrams showing which portion of a reflected wave is received according to target range;

Fig. 6 is a diagram showing one configuration example of a single-antenna transmit-receive FM-CW radar used in the present invention;

Figs. 7A, 7B, 7C, 7D, 7E, and 7F are diagrams for explaining the operation of an embodiment of the present invention;

Fig. 8 is a diagram showing the effect of suppressing the gain of a receiver amplifier in the first half portion of a receive timing interval;

Figs. 9A, 9B, 9C, and 9D are diagrams for explaining

the operation of the embodiment of the present invention;

Fig. 10 is a diagram showing another configuration example of the single-antenna transmit-receive FM-CW radar used in the present invention;

5 Figs. 11A, 11B, 11C, and 11D are diagrams for explaining an alternative embodiment of the present invention;

Figs. 12A and 12B are diagrams for explaining a modification of the alternative embodiment of the present
10 invention;

Fig. 13 is a diagram showing another configuration example of the single-antenna transmit-receive FM-CW radar used in the present invention;

Fig. 14 is a diagram showing another configuration
15 example of the single-antenna transmit-receive FM-CW radar used in the present invention;

Fig. 15 is a diagram showing the configuration of an amplifier A; and

Figs. 16A and 16B are graphs showing how the gain of
20 the amplifier A changes when a drain voltage or a gate voltage is varied.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before describing the radar apparatus of the present
25 invention, the principle of FM-CW radar will be described.

An FM-CW radar measures the distance to a target object, such as a vehicle traveling ahead, by transmitting a continuous wave frequency-modulated, for
30 example, in a triangular pattern. More specifically, the transmitted wave from the radar is reflected by the vehicle ahead, and the reflected signal is received and mixed with the transmitted signal to produce a beat signal (radar signal). This beat signal is fast Fourier
35 transformed to analyze the frequency. The frequency-analyzed beat signal exhibits a peak at which power becomes large in correspondence with the target. The

frequency corresponding to this peak is called the peak frequency. The peak frequency carries information about distance, and the peak frequency differs between the rising portion and falling portion of the triangular FM-CW wave due to the Doppler effect associated with the relative velocity with respect to the vehicle ahead. The distance and the relative velocity with respect to the vehicle ahead can be obtained from the peak frequencies in the rising and falling portions. If there is more than one vehicle traveling ahead, a pair of peak frequencies, one in each rising and falling portion, is generated for each vehicle. Forming pairs of peak frequencies in the rising and falling portions is called pairing.

Figs. 1A to 1C are diagrams for explaining the principle of the FM-CW radar when the relative velocity with respect to the target is 0. The transmitted wave is a triangular wave whose frequency changes as shown by a solid line in Fig. 1A. In the figure, f_0 is the center frequency of the transmitted wave, Δf is the FM modulation width, and T_m is the repetition period. The transmitted wave is reflected from the target and received by an antenna; the received wave is shown by a dashed line in Fig. 1A. The round trip time T , to and from the target, is given by $T = 2r/C$, where r is the distance (range) to the target and C is the velocity of radio wave propagation.

Here, the received wave is shifted in frequency from the transmitted signal (i.e., produces a beat) according to the distance between the radar and the target.

The frequency component f_b of the beat signal can be expressed by the following equation.

$$f_b = f_r = (4 \cdot \Delta f / C \cdot T_m) r \quad (1)$$

where f_r is the frequency due to the range (distance).

Figs. 2A to 2C, on the other hand, are diagrams for explaining the principle of the FM-CW radar when the

relative velocity with respect to the target is v . The frequency of the transmitted wave changes as shown by a solid line in Fig. 2A. The transmitted wave is reflected from the target and received by the antenna; the received wave is shown by a dashed line in Fig. 2A. Here, the received wave is shifted in frequency from the transmitted signal (i.e., produces a beat) according to the distance between the radar and the target.

In this case, as the relative velocity with respect to the target is v , a Doppler shift occurs, and the beat frequency component fb can be expressed by the following equation.

$$fb = fr \pm fd = (4 \cdot \Delta f / C \cdot T_m) r \pm (2 \cdot f_0 / C) v \quad (2)$$

where fr is the frequency due to the distance, and fd is the frequency due to the velocity.

~~The symbols in the above equation have the following meanings.~~

fb : Transmit beat frequency
 fr : Range (distance) frequency
 fd : Velocity frequency
 f_0 : Center frequency of transmitted wave
 Δf : Frequency modulation width
 T_m : Period of modulation wave
 C : Velocity of light (velocity of radio waves)
 T : Round trip time of radio wave to and from target object
 r : Range (distance) to target object
 v : Relative velocity with respect to target object

Fig. 3 is a diagram showing one configuration example of a single-antenna transmit-receive FM-CW radar. As shown, a modulating signal generator (MOD) 1 applies a modulating signal to a voltage-controlled oscillator (VCO) 2 for frequency modulation, and the frequency-modulated wave is passed through a directional coupler 3 and transmitted out from a transmitting/receiving antenna (ATR), while a portion of the transmitted signal is

separated by the directional coupler 3 and fed into a first mixer 4-1. The signal reflected from a target is received by the transmitting/receiving antenna (ART). SW8 is a transmit-receive switch which switches the antenna between transmission and reception in accordance with a signal supplied from a transmit-receive switching signal generator (OSC) 9 constructed from an oscillator. The OSC 9 generates a modulating signal of frequency f_{sw} for causing the SW 8 to switch the antenna between transmission and reception. The received signal is mixed in the first mixer 4-1 with the output signal of the voltage-controlled oscillator (VCO) 2 to produce an IF signal. The IF signal is mixed in a second mixer 4-2 with the modulating signal of frequency f_{sw} supplied from the OSC 9 and is thus downconverted, producing a beat signal. The beat signal is passed through a filter (F) 5, and is converted by an A/D converter (A/D) 6 into a digital signal; the digital signal is then supplied to a digital signal processor (DSP) 7 where signal processing such as a fast Fourier transform is applied to the digital signal to obtain distance, relative velocity, etc.

The power of the received signal received via the transmitting/receiving antenna and the power of the beat signal are as shown below. First, the power of the received signal, P_r , is expressed by the following equation.

$$P_r = \{(G^2 \cdot \lambda^2 \cdot \sigma \cdot P_t) / ((4\pi)^3 \cdot r^4)\} \cdot L_a \quad (3)$$

The symbols in the above equation have the following meanings.

G: Antenna gain

λ : Wavelength

σ : Cross-sectional area of reflecting object

P_t : Transmitter power

r: Range

L_a : Atmospheric attenuation factor

The power of the beat signal, P_b , is expressed by the following equation.

$$P_b = P_r \cdot C_{mix} \quad (4)$$

where C_{mix} is the conversion loss factor in the mixer.

5 Figs. 4A to 4D are diagrams showing timings for transmission, reception, etc. The SW 8 in Fig. 3 is switched by the signal of frequency f_{sw} (period T_{sw}) to switch the timing between transmission and reception. Fig. 4A shows the transmit timing interval, and Fig. 4B shows the return timing of the transmitted wave reflected from a target. Fig. 4C shows the receive timing interval; the reflected wave returned during this interval is received by the antenna ATR. Accordingly, when the reflected wave is returned at the timing shown in Fig. 4B, the actually received reflected wave is as shown in Fig. 4D.

As described above, in the single-antenna transmit-receive FM-CW radar, the transmit and receive timings are provided one alternating with the other, and the reflected wave, i.e., the transmitted wave returned by reflection from the target, is received. Further, as the receive timing interval is one half the cycle period T_{sw} of the transmit-receive switching frequency, the receiving efficiency is maximized when the delay time of the reflected wave is one half the cycle period; on the other hand, if the delay time is one cycle period, the reflected wave cannot be received.

Accordingly, to secure the desired detection range, the transmit-receive switching frequency must be selected so that the delay time of the reflected wave returned from the desired detection range will be less than one cycle period of the transmit-receive switching frequency.

Figs. 5A to 5D are diagrams showing which portion of the reflected wave is received according to the target range.

Fig. 5D is a diagram showing the receive timing interval (the same as that shown in Fig. 4C), and Fig. 5A

is a diagram showing the return timing, of the reflected wave, from a short-range target. As can be seen from the waveform shown in Fig. 5A, the reflected wave from the short-range target returns during the interval t_a to t_1 which is earlier than the receive timing interval t_0 to t_3 . Here, as a portion (from t_a to t_0) of the reflected wave returns earlier than the receive timing interval (t_0 to t_3), this portion is not received and, of the waves reflected from the short-range target, only the portion t_0 to t_1 is actually received.

Likewise, Fig. 5B is a diagram showing the return timing of the reflected wave from a mid-range target. In this case, as can be seen from the waveform shown in Fig. 5B, as the reflected wave returns during the interval t_b to t_2 which is earlier than the receive timing interval, only the portion t_0 to t_2 is actually received.

Fig. 5C is a diagram showing the return timing of the reflected wave from a long-range target. In this case, as the reflected wave returns during an interval that substantially coincides with the receive timing interval, most of the reflected wave is received.

[Embodiment 1]

Fig. 6 is a diagram schematically showing the configuration of a single-antenna transmit-receive FM-CW radar used in the present invention. A modulating signal generator (MOD) 1 applies a modulating signal to a voltage-controlled oscillator (VCO) 2 for frequency modulation, and the frequency-modulated wave is passed through a directional coupler 3 and transmitted out from a transmitting/receiving antenna (ATR), while a portion of the transmitted signal is separated by the directional coupler 3 and fed into a first mixer 4-1. The signal reflected from a target is received by the transmitting/receiving antenna (ART). SW8 is a transmit-receive switch which switches the antenna between transmission and reception in accordance with a switching signal of frequency f_{sw} supplied from a transmit-receive

switching signal generator (OSC) 9 constructed from an oscillator. "At" designates an amplifier provided in the transmitter, and "Ar" an amplifier provided in the receiver; the on/off operations of the amplifiers are controlled by the switching signal of frequency f_{sw} supplied from the transmit-receive switching signal generator (OSC) 9 constructed from an oscillator. The receiver amplifier Ar is provided with an inverter so that the amplifiers At and Ar are alternately turned on and off; that is, transmission is performed when the amplifier At is on, and reception is performed when the amplifier Ar is on.

The received signal is mixed in the first mixer 4-1 with the output signal of the voltage-controlled oscillator (VCO) 2 to produce an IF signal. The IF signal is mixed in a second mixer 4-2 with the modulating signal of frequency f_{sw} supplied from the OSC 9 and is thus downconverted, producing a beat signal. The beat signal is passed through a filter (F) 5, and is converted by an A/D converter (A/D) 6 into a digital signal; the digital signal is then supplied to a digital signal processor (DSP) 7 where signal processing such as a fast Fourier transform is applied to the digital signal to obtain distance, relative velocity, etc.

Figs. 7A to 7F are diagrams for explaining the operation of an embodiment according to the present invention. Fig. 7A shows the transmit timing interval, and Fig. 7B shows the return timing of the reflected wave which is received, with a finite time delay, after the transmit timing. Fig. 7C shows the receive timing interval. In the present invention, the gain of the receiver amplifier Ar in Fig. 6 is controlled. In this case, as shown by oblique hatching in Fig. 7C, the gain is suppressed in the leading edge portion of the receive timing interval, and the amount of suppression is gradually reduced in such a manner that, at a certain point in the interval, for example, at the midpoint, the

gain returns to the normal level.

Fig. 7D is a diagram showing the reflected wave received when the target is at a short range. In this case, as the reflected wave returns relatively early, the actually received portion of the reflected wave is only the portion t_0 to t_1 that falls within the receive timing interval t_0 to t_3 . On the other hand, in the present invention, as the gain of the receiver amplifier A_r is suppressed gradually from the leading edge toward the midpoint of the receive timing interval, as shown in Fig. 7C, the power of the received wave can be suppressed as shown in Fig. 7D.

Fig. 7E is a diagram showing the reflected wave received when the target is at mid range. In this case, the actually received portion of the reflected wave is only the portion t_0 to t_2 that falls within the receive timing interval t_0 to t_3 . In this case also, the power of the received wave can be suppressed as shown in Fig. 7E.

Fig. 7F is a diagram showing the reflected wave received when the target is at long range. In this case, as the return timing of the reflected wave substantially coincides with the receive timing interval t_0 to t_3 , most of the reflected wave is received. In the case of the reflected wave from a long-range target, the received power is small but, while the power of the received wave is suppressed gradually from the leading edge toward the midpoint as shown in Fig. 7F, the overall power of the received wave does not suffer much attenuation because the power is not suppressed in the portion from the midpoint toward the trailing edge.

In this way, according to the present invention, the shorter the target range, the more the power of the received reflected wave is suppressed; as a result, the dynamic range required of the receiver circuit can be reduced.

Fig. 8 is a diagram showing the effect of

suppressing the gain of the receiver amplifier A_r in the first half portion of the receive timing interval. In the figure, the horizontal axis represents the range r to the target, and the vertical axis the received power P_r .
5 The received power can be expressed by the previously given equation (3), and decays with the fourth power of the range r as shown by the curve P_{ra} . However, as can be seen from the curve P_{ra} , the received power at the antenna is large at short range, and a dynamic range as
10 large as G_a is required if the received power not only from short range but also from long range is to be handled.

On the other hand, the curve P_{rb} shows the variation of the received power as a function of the range when the
15 gain of the receiver amplifier A_r is suppressed. As shown by the curve P_{rb} , as the gain of the reflected wave from the short range is suppressed by the receiver amplifier A_r , the received power at the antenna for the short-range region is reduced, and the required dynamic
20 range is thus reduced to G_b which is smaller than G_a .

When the gain of the reflected wave from a short range is suppressed, the received power of the reflected wave from a short-range target (the output of the amplifier A_r) decreases as shown by the curve P_{rb} , but
25 the received power of the reflected wave from a mid-range or long-range target is substantially the same as when the gain is not suppressed. Accordingly, signals ranging from short range to long range can be handled with a small dynamic range.

30 In the above description, the received power is suppressed by controlling the gain of the receiver amplifier A_r but, alternatively, the received power may be suppressed by controlling the gain of the transmitter amplifier A_t and suppressing the transmitting power in
35 the second half portion of the transmit wave transmit timing interval. In the latter case, the amount of suppression is reduced gradually or stepwise from the

trailing edge toward the midpoint of the transmit timing interval. In other words, the amount of suppression is increased gradually or stepwise from the midpoint toward the trailing edge of the transmit timing interval.

5 Figs. 9A to 9D are diagrams showing the transmit timing interval and the method of suppression for the above case. As shown in Fig. 9A, the amount of suppression is increased gradually from the midpoint toward the trailing edge of the transmit timing interval.

10 Figs. 9B to 9D are diagrams showing the reflected waves from short-range, mid-range, and long-range targets, respectively. The reflected waves shown here correspond to the reflected waves shown in Figs. 7D to 7F, respectively but, as the portion where the power is
15 suppressed is the second half portion, the amount of suppression increases gradually from the midpoint toward the trailing edge, conversely to the case of Figs. 7D to 7F.

20 Alternatively, the gains of both the transmitter and receiver amplifiers may be controlled to achieve the same effect. This also applies to the embodiments hereinafter described.

[Embodiment 2]

25 Fig. 10 is a diagram schematically showing the configuration of a single-antenna transmit-receive FM-CW radar used in the present invention. A modulating signal generator (MOD) 1 applies a modulating signal to a voltage-controlled oscillator (VCO) 2 for frequency modulation, and the frequency-modulated wave is passed
30 through a directional coupler 3 and transmitted out from a transmitting/receiving antenna (ATR), while a portion of the transmitted signal is separated by the directional coupler 3 and fed into a first mixer 4-1. The signal reflected from a target is received by the
35 transmitting/receiving antenna (ART). Reference numeral 10 indicates a transmit-receive duplexer. "At" designates an amplifier provided in the transmitter, and

"Ar" an amplifier provided in the receiver; the on/off operations of the amplifiers are controlled by a switching signal of frequency f_{sw} supplied from a transmit-receive switching signal generator (OSC) 9 constructed from an oscillator. The receiver amplifier Ar is provided with an inverter so that the amplifiers At and Ar are alternately turned on and off; that is, transmission is performed when the amplifier At is on, and reception is performed when the amplifier Ar is on.

The received signal is mixed in the first mixer 4-1 with the output signal of the voltage-controlled oscillator (VCO) 2 to produce an IF signal. The IF signal is mixed in a second mixer 4-2 with the modulating signal of frequency f_{sw} supplied from the OSC 9 and is thus downconverted, producing a beat signal. The beat signal is passed through a filter (F) 5, and is converted by an A/D converter (A/D) 6 into a digital signal; the digital signal is then supplied to a digital signal processor (DSP) 7 where signal processing, such as a fast Fourier transform, is applied to the digital signal to obtain distance, relative velocity, etc.

The operation described with reference to Figs. 7A to 7F and Figs. 9A to 9D is also performed in the single-antenna transmit-receive FM-CW radar shown in Fig. 10.

[Embodiment 3]

Figs. 11A to 11D are diagrams for explaining the operation of another embodiment of the present invention. Fig. 11A shows the transmit timing interval, and Fig. 11B shows the return timing of the reflected wave which is received with a finite time delay from the transmit timing. Fig. 11C shows the receive timing interval; here, the receiver amplifier Ar in Fig. 10 is controlled as in the case of the first embodiment. In the present embodiment, the amount of suppression is varied stepwise in the first half portion of the receive timing interval in such a manner that the gain returns to the normal level, for example, at the midpoint of the interval.

Fig. 11D shows a waveform corresponding to that shown in Fig. 7D, that is, the reflected wave received when the target is at a short range. In this case, as the target is at a short range, the reflected wave is received in the first half portion of the receive timing, but not received in the second half portion. In this embodiment, as the amount of gain suppression of the receiver amplifier Ar is varied stepwise from the leading edge toward the midpoint of the receive timing interval, the dynamic range of the reflected wave returned from the short-range target can be reduced.

Figs. 12A and 12B are diagrams each showing a modification of the third embodiment; here, the amount of gain suppression of the receiver amplifier Ar is varied in a number of steps as in the third embodiment, but the number of steps is increased. Increasing the number of steps has the effect of allowing fine control of the amount of gain suppression.

[Embodiment 4]

Fig. 13 is a diagram showing still another embodiment of a single-antenna transmit-receive FM-CW radar according to the present invention. The single-antenna transmit-receive FM-CW radar shown in Fig. 13 differs from the configuration shown in Fig. 10 in that a plurality of receiver amplifiers, for example, two receiver amplifiers Ar1 and Ar2, are provided, one amplifier Ar1 being provided with a gain control means for controlling the gain and the other amplifier Ar2 provided with a means for performing switching between transmission and reception.

In the single-antenna transmit-receive FM-CW radar shown in Fig. 13, the gain is controlled in the receiver amplifier Ar1 but, instead, the gain may be controlled in the other receiver amplifier Ar2. Alternatively, the received power may be suppressed by controlling the gain of the transmit wave in the transmitter amplifier At in such a manner as to suppress the gain in the second half

portion of the transmit wave transmit timing interval.

[Embodiment 5]

Fig. 14 is a diagram showing yet another embodiment of a single-antenna transmit-receive FM-CW radar according to the present invention. The single-antenna transmit-receive FM-CW radar shown in Fig. 14 differs from the configuration shown in Fig. 10 in that multipliers M_t and M_r , respectively, are provided in the transmitter signal path and/or the branch section branching off the directional coupler in the transmitter.

In this embodiment, the power of the transmit wave in the second half of the transmit timing interval is suppressed and is modulated by varying the voltage applied to the multiplier (M_t) provided in the transmitter signal path. Alternatively, the power in the first half of the transmit timing interval may be suppressed and modulated by varying the voltage applied to the multiplier (M_r) provided in the branch section. In this way, the received power can be suppressed.

[Embodiment 6]

Fig. 15 is a diagram showing the configuration of an amplifier A. A signal is input to a gate G and output from a drain D.

Figs. 16A and 16B are graphs showing how the gain of the amplifier A changes when the bias voltage to the drain D or gate G is varied. Fig. 16A shows the change in gain when the drain bias voltage is varied from V_B to V_A while holding the gate voltage V_G constant. When the bias voltage V_B is applied, the gain is as low as G_B ; at this time, the amplifier A is almost inoperative and is thus essentially off. On the other hand, when the bias voltage V_A is applied, the gain is as high as G_A ; at this time, the amplifier A is in the operating state.

When controlling the gain of the amplifier to suppress the gain in the first half of the receive timing interval or the second half portion of the transmit timing interval, as in the present invention, the drain

voltage is gradually varied from VB to VA. When suppressing the gain in a stepwise manner, the drain voltage is varied from VB to VA in a stepwise manner.

5 Fig. 16B shows the change in gain when the gate bias voltage is varied from VB to VA while holding the drain voltage VD constant. When the bias voltage VB is applied, the gain is as low as GB; at this time, the amplifier A is almost inoperative and is thus, essentially, off. On the other hand, when the bias
10 voltage VA is applied, the gain is as high as GA; at this time, the amplifier A is in the operating state.

When controlling the gain of the amplifier to suppress the gain in the first half of the receive timing interval or the second half portion of the transmit
15 timing interval, as in the present invention, the gate voltage is gradually varied from VB to VA. When suppressing the gain in a stepwise manner, the gate voltage is varied from VB to VA in a stepwise manner.
